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A Compact Transmitter Array to Reproduce Neutrino's Acoustic Signature in Water †

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Abstract: In this work, we present a prototype of a compact linear array with three elements that is able to reproduce the acoustic signature of Ultra High Energy (UHE) neutrino interaction in water using the parametric acoustic effect. To mimic this signal is non-trivial since it is a very directive bipolar transient signal with cylindrical symmetry. We characterize the prototype by measuring the signal waveform, the attenuation, intensity variation and directivity, both with numerical simulations and experimentally in a pool. We also study different kind of signals to conclude the best application for the array. The results confirm the utility of this array for the proposed application for marine neutrino telescopes.

Keywords: Underwater acoustic; Transmitter array; UHE neutrino; Parametric effect

1. Introduction

Few decades ago, the acoustic technique was proposed for the detection of UHE neutrinos [1]. When there is a UHE neutrino interaction in water, a shower of particles is produced, so its energy is released in a small cylindrical-like volume of a few centimeters in radius and several meters in length. This local heating in an almost instantaneous time leads to a short pressure pulse signal with bipolar shape in time and very directive pattern (pancake-like), being emitted perpendicularly to the shower axis. The feasibility of the technique is still under discussion and several experiments and tools have been proposed to test it [2,3,4]. This technique could be implemented in the KM3NeT telescope, which is a new optical-based deep-sea neutrino telescope under construction with a volume of several cubic kilometers. The fact that this facility has to integrate hundreds of acoustic sensors in the acoustic positioning system for calibration purposes triggers the idea of using the sensors for acoustic detection of neutrinos as well..

If the KM3NeT finally use the acoustics sensors for neutrino detection, it is necessary that these sensors are well calibrated for this purpose. This is the reason to use an emitter able to reproduce neutrino's acoustic signature and, thus, the feasibility of the technique could be studied quite directly.

This proceeding describes the design of the emitter array based on simulations and it also shows the first experimental results to characterize the array.

2. Reproduction of the Neutrino's Acoustic Signature with Parametric Effect

G.A. Askaryan predicted that a thermo-acoustic pulse is produced after a UHE neutrino interaction in water that develops a shower of particles almost at the speed of light with a very localized deposition of energy. The acoustic signal is very singular because it is very directive although it is composed by low-ultrasonic frequency, between 2 to 50 kHz (see Fig. 1). Neutrino's acoustic signature is similar to a bipolar pulse with ~1mPa of amplitude for a 1 EeV neutrino measured at 1 km [4].

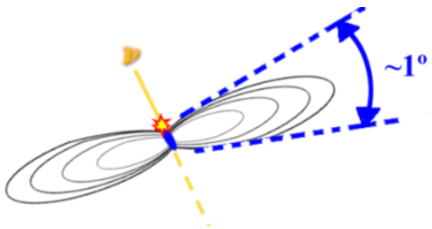


Figure 1. Scheme of the development of the directive acoustic pulse by a neutrino interaction with water (or ice) [5].

To reproduce the directive acoustic bipolar pulse, we will use the parametric effect [3]. This principle consists in emitting a beam with two close frequencies with high energy (1st beam). The propagation in the non-linear medium will produce combinations of these two frequencies (2nd beam). Specifically, the difference frequency of the 1st beam is used to get low-ultrasonic frequency with a pronounced directivity [6].

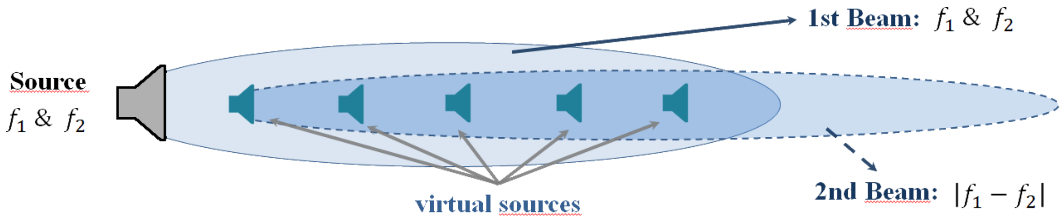


Figure 2. Scheme of parametric effect's generation. Emitting two narrow powerful beams at different frequencies (1st beam), combinations of these frequencies (2nd beam) along the medium are produced.

The waveform of the signal produced by parametric effect can be predicted with the Eq 1.

$$p(x,t) = \left(1 + \frac{B}{2A}\right) \frac{P^2 S}{16\pi \rho c^4 \alpha x} \frac{\delta^2}{\delta t^2} \left[f\left(t - \frac{x}{c}\right)\right]^2 \sim \frac{\delta^2}{\delta t^2} f^2, \quad (1)$$

where p is the resulting pressure wave along x, space and t, time, B/A is the non-linear parameter of the medium, P is the pressure of the 1st beam, S is the area of the vibrating surface, ρ is the density of the medium, c is the velocity of the propagation, α is the absorption coefficient in medium and f is the envelope of the modulation in emitted signal. So, it is proportional to the second derivative of the square of the envelope function of the emitted signal.

3. Design and Development a Transmitter Array

The design of the array begun with the study of a single element to select the type of transmitter [7]. The single element elected is a commercial piezo-ceramic cylindrical transducer (UCE-534541) mixed with polyurethane EL241F as matching and aluminum as backing (see Fig. 3). It has a resonance frequency around the 495 kHz (see Fig. 4).

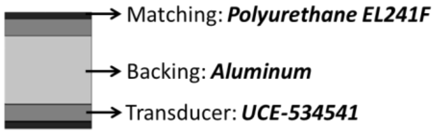
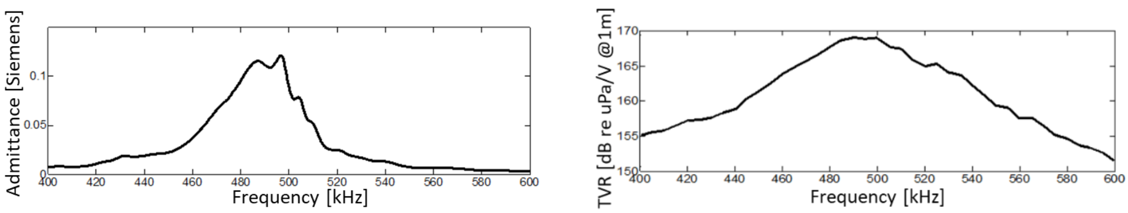


Figure 3. Scheme of materials used in the acoustic emitter sensor of the array. The emitter is an UCE-534541 piezo-ceramic recovered for polyurethane EL241F in the outside layer as matching, and aluminum in the inside layer as backing.

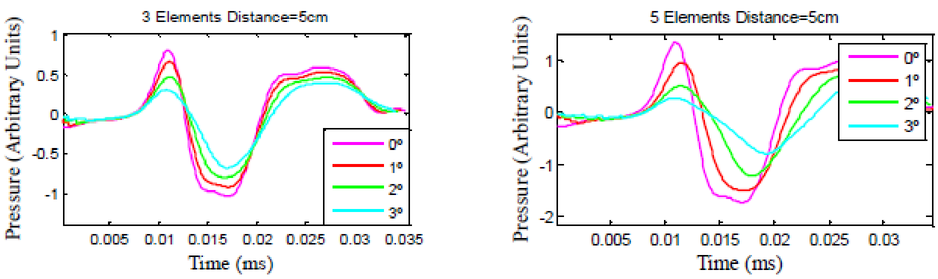


(**a**) (**b**)

Figure 4. Measures of the acoustic emitter sensor: (a) Admittance. (b) Transmitter Voltage Response (TVR).

The approach of the acoustic array is to accomplish an emission of a bipolar pulse signal with similar characteristics to the acoustic signal produced by a 10^{20} eV neutrino interacting in water at a distance of 1km, with an amplitude of the bipolar pulse of about 10 mPa (corresponding basically to a 2-50 kHz frequency range) with an opening angle of 1° approximately, emulating the neutrino's acoustic signal in water [1].

The first studies about parametric emission with a bipolar pulse in a single element permits simulating the opening angle of the signal at 1km from the emission of three and five elements of the array studying the best distances between emitter elements considering the propagation of the wave (see Fig. 5). The propagation was performed taking into account the losses from the medium absorption coefficient (under the condition of the KM3NeT telescope) and the spherical divergence.

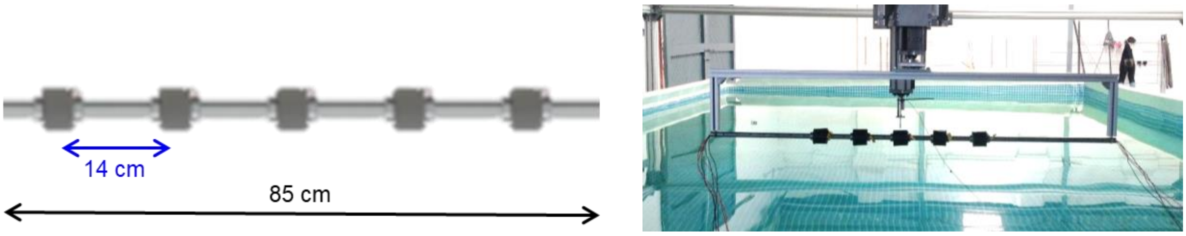


(**a**) (**b**)

Figure 5. Example of simulation result for 4 different angles about opening angle of the signal in the propagation at 1 km: (a) Result for 3 elements in the array with 5 cm of distance between them. (b) Result for 5 elements in the array with 5 cm of distance between them [5].

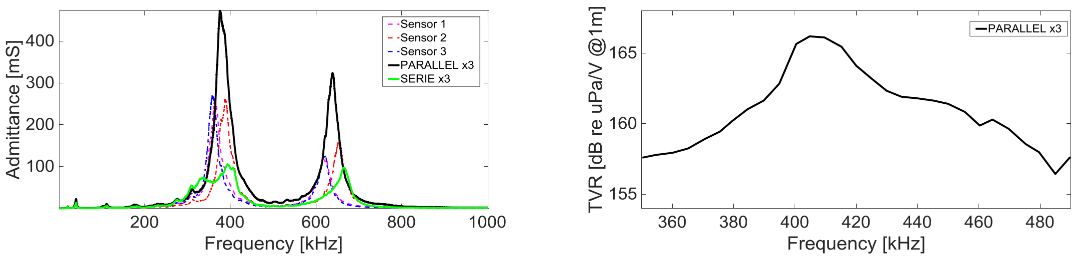
Finally, the studies indicate that the optimum distance between elements is 14cm.

Once the distance between elements is selected, the next step was to develop an array with 5 emitter elements (see Fig. 6). When the elements were installed in array, the common subjection (aluminum bar) produces that the resonance frequency experiment a displacement. Specifically, the resonance frequency in the element assembled in the array bar appears around 380 kHz (not 495 kHz) with secondary resonance around 640 kHz (see Fig. 7).



(**a**) (**b**)

Figure 6. Final design of the array: (a) Scheme about its configuration. (b) Picture of it in the pool at the UPV laboratory in Gandia's harbor.



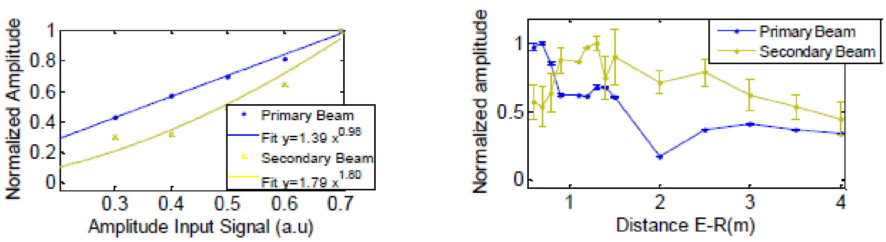
(**a**) (**b**)

Figure 7. Measures of acoustic emitter array (3 elements): (a) Admittance (b) Transmitter Voltage Response (TVR) measure in dB refer to µPa/V at 1meter of distance with 3 elements in parallel.

3. Results

The experimental results in this paper show the characterization of the array with three elements connected in parallel. The characterization was performed for the first beam (linear range) and for the second beam (parametric range).

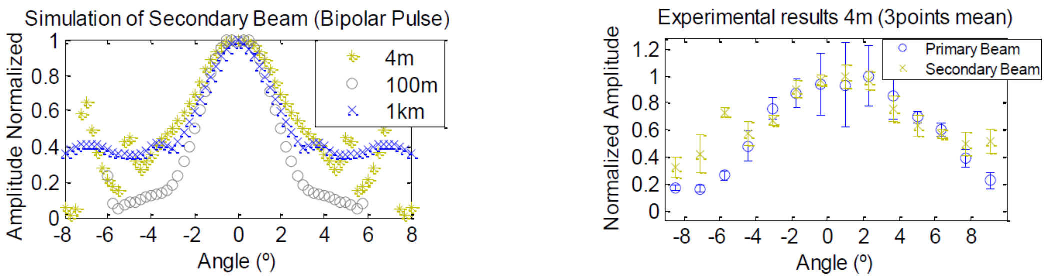
After characterizing the array in terms of Admittance and Transmitter Voltage Response (TVR) (see Fig. 7), the array in parallel configuration was studied in deep. For this, the generation of the secondary parametric acoustic bipolar pulse as a function of the feeding voltage was studied, see Fig. 8.a). The different behavior of primary beam (linear) can be directly compared to the one of the of the secondary beam (parametric generation). It can also be noticed the difference in generation and propagation in the study of signals aa a function of the distance between emitter array and receiver sensor, as shown in Fig. 8.b).



(**a**) (**b**)

Figure 8. Characterization measures in array with three elements: (a) Variation of voltage to evidencing the parametric effect appearance. (b) The amplitude evolution of two beams from 1 to 4 meters [5].

The directivity of the array with acoustic bipolar pulse is shown in Fig. 9. In Fig. 9.a the directivity obtained by simulations for the array, based on the experimentally measured directivity of a single element, is presented for distances of 4, 100 and 1000 meters. In Fig. 9.b, the experimental measures with the array for a distance between array and receiver of 4 m is shown.



(**a**) (**b**)

Figure 9. Directivity of array with three elements: (**a**) Simulation for different distances (b) Experimental measure for 4 m distance [5].

4. Conclusions and Future Step

Based on the first studies of the prototype array, we can conclude that the designed array is able to emit an acoustic signal that mimics the UHE neutrino acoustic signature. The prototype with three elements is characterized for parametric generation. A similar directivity is obtained for primary and secondary beams, reaching the goal of having a final directionality of a few degrees (FWHM in amplitude) for the bipolar pulse.

The next step in this prototype is improving the electronics so to increase the power of the signal for the use over longer distances and for *in situ* tests in KM3NeT.

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Conflicts of Interest: The authors declare no conflict of interest.

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